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(54) Title: EQUALIZATION TECHNIQUES FOR COMMUNICATION SYSTEMS USING ORTHOGONAL SIGNALING
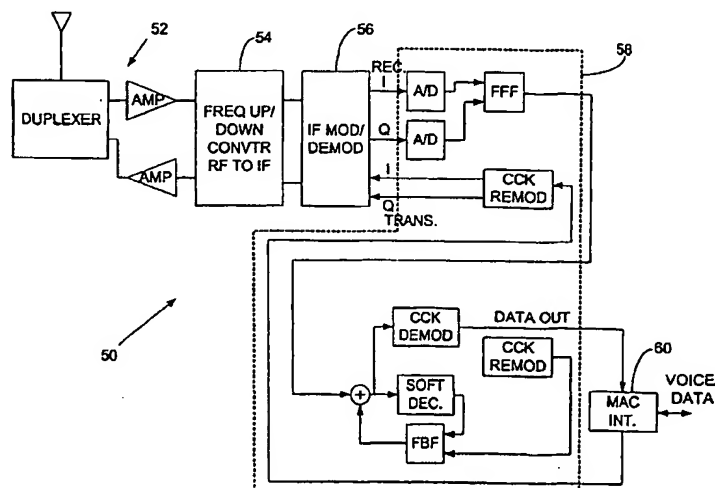
(57) Abstract: Devices, systems and methods for equalizing orthogonally keyed, and more particularly, complementary code keyed signals. Soft decision functionality output based on said signals is employed to produce information that is fed back to said complementary code keyed signals, in order to reduce interference, and importantly, self interference caused by multipath propagation delays, in the complementary code keyed signals. Additionally, information based on said complementary code keyed signals, which may be information that is based on remapping the signals after they are demodulated in order to correspond to complementary code keying symbols, may be fed back into said complementary code keyed signals in order to, among other things, reduce interference and take advantage of the processing gain resulting from complementary code keying processing techniques.

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Equalization Techniques for Communication Systems
Using Orthogonal Signaling

The present invention relates to systems and methods for improving performance of systems which use orthogonal signaling, including complementary code keying, and more particularly, for improving such performance through new equalization techniques.

1. Background and Summary.

Cordless and cellular phones, pagers, wireless capable palm computing devices and other similar wireless related data devices and equipment are becoming increasingly ubiquitous. These present a mass market opportunity for wireless data terminals as well as broadband wireless services. There are two distinct, yet complementary, system approaches for addressing this increased mobility demand. First are enhanced cellular networks with increased bit rate capabilities which enable greater mobility and globalized communications possibilities for users because of (among other things) handoff and roaming functionality. Second are non-centralized wireless local area networks (LAN's), which offer orders of magnitude higher data rates through coverage area restriction to provide substantially reduced signal attenuation and multipath delay spread. Both system approaches have been the focus of extensive research and standards activities.

Major considerations for the choice of an air interface or wireless technique to enable wireless data include the following considerations. First, flexible data rates are needed in order to support bandwidth-on-demand services. Accordingly, the wireless link must offer a high peak data rate and a means for traffic multiplexing. Second, low power consumption is needed because users obviously prefer wireless terminals whose batteries last longer. In addition, broadband services will increasingly require increased power for both RF radiation (to overcome the increased thermal noise bandwidth) and

signal processing. Advanced signal processing techniques will enable the receiver to operate at a low signal-to-noise ratio (SNR), thus reducing the RF power requirement. On the other hand, although advances in integrated circuits promise power reduction in future signal processing devices, this alone may not compensate for the ever more complex demand for broadband wireless receivers. It is important that the air interface technique emphasize reduced complexity.

Third, high frequency reuse efficiency is preferred for several reasons. Greater frequency reuse translates into lower required bandwidth. This is important because, due to spectrum congestion, broadband services will face limits on the total amount of bandwidth available. High frequency reuse can be achieved with a number of cochannel interference management techniques, such as improved engineering, power control, frequency hopping, and dynamic channel assignment. In addition, receiver techniques such as interference cancellation and smart antennas will enable the receiver to operate at a low required signal-to-interference ratio (SIR).

Fourth, low transmission overhead is preferable, since overhead degrades the degree of information payload in the transmission. Transmission overhead includes guard bands, guard times, coding redundancy, and all the bandwidth (frequency / time / code) dedicated for the purpose of receiver training and acquisition.

Fifth, robustness is obviously desirable; the air interface technique must be robust to different service environments, channel fading characteristics, and high mobility.

In the US, most consumer wireless communications devices operate in the unlicensed bands, e.g., the ISM band. The rules require some amount of spectrum spreading to reduce interference between different devices. In order to permit a high data rate capability of 11 Mb/s consistent with the data rate flexibility, low power consumption, high frequency reuse efficiency, low transmission overhead and robustness parameters mentioned above, the IEEE

802.11 standards committee has recently specified a modulation technique, called complementary code keying (CCK), as a high-rate extension to the existing 1 and 2 Mb/s direct sequence spread spectrum (DSSS) approaches.

CCK as proposed by the IEEE 802.11 standards committee is a form of orthogonal signaling in which the information data is mapped into nearly orthogonal sequences (or code symbols) to be transmitted. The receiver correlates the received signal with all possible transmit waveforms to find the most likely code symbol, from which the information data is recovered through reverse mapping. In order to improve transmission efficiency, the absolute phase of the orthogonal waveform is also used to carry information. The CCK specified by the IEEE 802.11 committee takes each 8 bits of information data and converts it into one of the 256 possible 8-chip-long CCK code symbols, where each chip is quaternary phase modulated. Thus, at a symbol rate of 1.375 MHz, a bit rate (= chip rate) of 8 x 1.375 = 11 Mb/s is achieved.

CCK aims to deliver on four goals the IEEE 802.11 committee deemed critical—concerning speed, interoperability, bandwidth usage and worldwide compatibility. Addressing the speed issue, CCK can deliver very robust Ethernet-equivalent data rates of better than 10 Mb/s. Interoperability is enhanced because this approach allows downshifting that makes it interoperable with existing 1 and 2 Mb/s 802.11 networks. CCK operates within the existing DSSS 1 and 2 Mb/s channels of the 2.4 GHz ISM band. And, like the 1 and 2 Mb/s standard, this extension is truly compatible with worldwide standards developed by global regulatory bodies such as the FCC, ETSI, and the MKK.

In addition to meeting those critical goals, CCK provides another important characteristic -- strong multipath interference properties. One of the main benefits of CCK is its ability to handle multipath interference. In multipath conditions, CCK's absence of simultaneous orthogonal signals on the in-phase (I) and quadrature (Q) rails (which exist in other orthogonal signaling schemes) serves to minimize cross rail interference. This allows CCK-based devices to be

less susceptible to multipath interference, which in turn allows these WLAN devices to provide better system performance. This is important, because indoor wireless communication channels are characterized by multipath propagation, which causes delay spread and intersymbol interference (ISI) to high data rate digital transmission systems.

However, while CCK is more robust to multipath propagation than most other modulation techniques, such robustness alone is insufficient to combat totally the effects of indoor wireless channels operating at a data rate of 11Mb/s. Multipath delay spread also causes inter-*chip* interference (ICI) which affects the orthogonality between different CCK code symbols. Accordingly, it is desirable that the 11 Mb/s WLAN receiver be equipped with an equalizer capable of eliminating both ICI and ISI or at least reducing or minimizing these more efficiently and effectively, in a low cost, robust implementation compatible with the criteria discussed above.

2.   Brief Description of the Drawings.

Fig. 1 is a functional block diagram which shows a conventional decision feedback equalizer.

Fig. 2 is a functional block diagram which shows one system and technique for use of a decision feedback equalizer to equalize complementary code keyed or other orthogonal signals.

Fig. 3 is a diagram which schematically represents structure and format of a complementary code keyed symbols.

Fig. 4 is a functional block diagram which shows a preferred embodiment of a system and technique according to the present invention for equalizing complementary code keyed or other orthogonal signals.

Fig. 5 is a diagram which shows computer-predicted performance of various equalizing techniques.

Fig. 6 is a diagram which shows the multipath delay profile employed to generate the data shown in Fig. 5.

Fig. 7 is a diagram which shows effects of certain digital implementations of techniques according to the present invention.

Fig. 8 is a functional block diagram of a transceiver which incorporates devices and processes according to the present invention.

3.   Detailed Description.

Decision feedback equalization is a well-known technique for mitigating ISI. A decision feedback equalizer (DFE), shown generally with numeral 10, consists of a feedforward filter (FFF) 12 and a feedback filter (FBF) 14, as shown in Fig. 1. Hard decision functionality or slicer 16 feeds hard decision information to the FBF. The FBF uses already-detected data to cancel ISI from past data symbols so that the FFF only has to suppress ISI from future data symbols. A DFE is suitable for high data rate applications because it is implementable with low complexity compared to other equalization techniques. See, for instance, S. L. Ariyavisitakul and G. M. Durant, "A Broadband Wireless Packet Technique Based On Coding Diversity And Equalization," *IEEE Communications Magazine*, 110 (July 1998) ("Ariyavisitakul and Durant") which is incorporated herein by reference.

In order to apply DFE to CCK (or any orthogonal signaling system), a straightforward approach is to use the DFE to equalize the signal before CCK symbol detection. In this case, the DFE has the same structure as Fig. 1, but it operates on each chip of the CCK symbol as if the chip was a quaternary phase shift keying (QPSK) symbol. The drawback of this approach is that, since the processing gain of CCK is not utilized, the decisions made by the DFE will have a relatively high error probability, and the decision errors will trigger improper ICI and ISI cancellation which affects the final CCK detection output. As a result, a CCK system which uses a DFE as a predetection equalizer will perform only as well as a non-spreading QPSK system at high signal-to-noise ratio (SNR).

The processing gain of CCK can be utilized by feeding back the more reliable output of the CCK symbol detector to the DFE. This requires a data to

CCK symbol remapper (or, simply for convenience in this document, but in a non-limiting way, "remapper" or "remodulator") which maps the decided data into necessary CCK chip waveforms for ISI cancellation by the FBF (see Fig. 2). Put another way, once a decision is made on which 8-ary CCK symbol has been transmitted, the receiver needs to feedback the chip waveform corresponding to that symbol to the equalizer. Given that all 256 possible CCK symbols can correspond to proxies such as integers: 0, 1, 2, ..., >255, the invention contemplates any way to map the proxy corresponding to the decided symbol into a CCK symbol waveform with 8 chips. These chip values may then be used in the feedback filter of the equalizer. In this way, devices and processes according to the present invention are mapping information data into CCK symbol waveforms, and any such process for mapping is referred to herein as remodulation or remapping. Such remapping can be done using remodulation techniques, but other techniques may be used as well.

The demodulator 18 and remapper 20 are shown in Fig. 2, as are FFF 22 and FBF 24 and hard decision functionality 26 in equalizer 28. The use of more reliable decisions improves the DFE performance as well as the error performance of the final CCK detection output. However, since the CCK decision is available only once every 8 chips, the sliced output of the DFE is still needed for the remaining ICI cancellation, depending on which chip is currently being equalized. For example, referring to Fig. 3, if chip #0 of the current CCK symbol is being equalized, past CCK decisions are sufficient to create all the waveforms necessary for ISI and ICI cancellation. However, if chip #7 of the current CCK symbol is being equalized, the receiver needs to use the sliced output of the DFE corresponding to chips #0 to #6 of the current CCK symbol to perform ICI cancellation. Therefore, this technique is still affected by chip decision errors (although to a lesser degree compared to the predetection DFE scheme mentioned above).

The present invention employs a DFE for equalization of CCK or any orthogonal signaling scheme. One embodiment of a system according to the

present invention, which employs methods according to the present invention, is shown in Fig. 4. Fig 4 shows an equalizer 30 which may use conventional demodulator 32, remapper 34, FFF 36, and FBF 38. Similar to what is shown in Fig. 2, both the DFE output and the CCK decisions are used as input to FBF 38. However, instead of using a hard decided DFE output, the output of the DFE is passed through soft decision functionality 40 in order to use the soft-decided chip value for ICI cancellation. Functionality 40, as is the case with demodulator 32, remapper 34, FFF 36, FBF 38 and other circuits, need not be implemented in discrete components or devices, but may be implemented in any desirable fashion. As an example, FFF 36 and FBF 38 may be implemented using a series of taps located in the same or proximate geographical area to each other, in a single integrated circuit. By using CCK decisions, reliable ISI cancellation can be achieved (similar to the method in Fig. 2). By using soft chip feedback, the ICI may not be completely canceled, but the impact of decision errors is minimized due to the fact that the soft-decided value is likely to be small when the chip is not reliable.

Any desired soft decision functions may be employed. For example, one form of such a function is a hyperbolic tangent function. If the function is overly steep, the decision is overly hard and therefore less preferred for at least the reasons mentioned in the preceding paragraph. If too soft, residual noise may be excessive. Soft decision functions, techniques and devices are disclosed in S. L. Ariyavisitakul and Y. Li, Joint Coding and Decision Feedback Equalization for Broadband Wireless Channels, 16 IEEE J. Selected Areas in Communications, 1670 (No. 9, December 1998) ("Ariyavisitakul and Li"), which is incorporated herein by this reference.

The use of soft decisions has been proposed in the past (including in Ariyavisitakul & Li) exclusively for the purpose of minimizing the effect of error propagation on subsequent error correction decoding. This technique applies to processes according to the present invention. An optimum approach for computing soft decisions involves averaging all possible values of the transmit

symbols at time n, $x_n (x_n = \pm 1 \pm j \text{ for QPSK})$, weighted by their "a posteriori probabilities."

The soft decision $\tilde{x}_n$ is a function of the present and past DFE output sequence $\{y_n, y_{n-1}, y_{n-2} \cdots y_{n-M}\}$:

$$\tilde{x}_n = \sum_{\text{all possible values of } x_n} x_n P\left(x_n | y_n, y_{n-1}, y_{n-2} \cdots y_{n-M}\right).$$

The a posteriori probability $P(x_n | y_n, y_{n-1}, y_{n-2} ..)$ needs to be computed recursively, and the complexity of such computation grows exponentially with the system memory M. Although suboptimum, Ariyavisitakul & Li point out that a significant improvement can be achieved by assuming M = 0, i.e.,

$$\tilde{x}_n = \sum_{\text{all } x_n} x_n P\left(x_n | y_n\right)$$

$$= f(y_n)$$

which results in the use of a hyperbolic tangent function.

The soft decision function according to the preferred embodiment is:

$$f(y) = \frac{1}{\sqrt{2}} \left\{ \tanh\left[\sqrt{2}\gamma \, \text{Re}(y)\right] + j \tanh\left[\sqrt{2}\gamma \, \text{Im}(y)\right] \right\}$$

where y is the input, whose real part and imaginary parts are denoted by Re(y) and Im(y), and γ is a parameter which controls the softness of the function. In theory, γ

should be set according to the measured signal-to-noise ratio (SNR) at the output of the equalizer. The higher the SNR, the harder the function. It is well known that the SNR can be computed from the mean-square error (MSE) obtained during equalizer training as:

$$\text{SNR} = \frac{1 - \text{MSE}}{\text{MSE}}$$

However, this requires the DFE to pass on the value of MSE, and the soft function to have multiple inputs, which can significantly complicate the implementation.

It was discussed in Ariyavisitakul & Li that γ can in fact be set as a fixed parameter without significantly degrading the performance of an error correction decoder. This is the case for equalizing orthogonally keyed signals and more specifically complementary code keyed signals. From an empirical approach, γ is chosen to be 3dB (i.e., $\gamma = 2$) according to the results of the Ariyavisitakul and Li article. However, since the receiver performance is not necessarily very sensitive to the choice of γ, any value of γ within a broad vicinity of $\gamma = 2$ may be usable. The value of γ may be chosen as a function of the signal to noise ratio at the equalizer output, or of any other desirable signal, and in any event is not limited to the 2 or values in that vicinity for appropriate results.

One way to implement $f(y)$ digitally is by using a look-up table approach. A read only memory (ROM) or other memory as appropriate can be used to store all possible values of $f(y)$ corresponding to a practical range of y. During each symbol period, the sampled output of the DFE, y_n is translated to the appropriate address to read $f(y_n)$ from the ROM.

Another way to implement $f(y)$ digitally is linear approximation. Piecewise linear approximation of $f(y)$ may lead to much simpler implementation, but may have an impact on performance. Figure 7 visually illustrates the nature and extent of such potential error.

Fig. 8 is a functional block diagram showing one transceiver which can include equalization processes and devices according to the present invention. Fig. 8 should not be interpreted or construed to limit the invention to any particular hardware and / or software implementation, as should not any description in this document. Any form of radio apparatus which performs modulation and/or demodulation that is adapted or adaptable to devices and processes according to the present invention is appropriate to consider as a system within the scope of the invention. Subject to that, Fig. 8 shows a transceiver 50 which includes an RF stage 52 which in turn can include conventional duplexing and amplification circuits, and which is coupled to one or

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more conversion stages 54 and 56. The IF modulation / demodulation circuits 56 convert the signal into baseband (I) (Q) waveforms, and are coupled to circuits 58 according to the present invention, such as are described above, for performing processes according to the present invention. Those circuits 58 may interface to appropriate conventional or unconventional media access control (MAC) circuits 60 for handling voice, data and other signals. Transceiver 50 may form part of a wireless LAN, or one of the various pieces of equipment in networks such as are disclosed in U.S.S.N. 09/229,848, filed January 12, 1999, entitled "Wireless Communications Gateway For A Small Home Or Office," U.S.S.N. 09/083,726, filed May 22, 1998, entitled "Communications Web for PSTN Subscribers", U.S.S.N. 08/843700, filed April 16, 1997, entitled "Communications Web for PSTN Subscribers," U.S.S.N. 08/709,597 filed September 9, 1996 entitled "Home Personal Communications System," and/or U.S. Patent No. 5,555,258 issued September 10, 1996, all of which are incorporated into this document by reference as if fully set forth herein.

In order to demonstrate the improved performance of systems according to the present invention, a computer simulation was performed to evaluate the CCK radio link performance of systems and techniques according to the present invention under typical indoor wireless fading channels. An example of the results is shown in Fig. 5. The measure of performance is the packet error rate (PER), where each packet contains 400 payload bits. The multipath delay profile employed is shown in Fig. 6; this delay profile is proposed by the Joint Technical Committee T1/E1 (JTC) to represent a severe multipath environment within a commercial building. Rayleigh fading is superimposed on each path. The maximum path delay is 2.7 μs, i.e., about 29 chip periods. These results are based on an assumed use of a DFE with 5 feedforward taps and 30 feedback taps. For comparison, performance of the two other schemes mentioned earlier is provided, in addition to predicted performance with no equalization: (a) the predetection DFE scheme, and (b) the DFE method in Fig. 2 (with CCK symbol feedback). At 10% PER, systems and methods according

to the present invention provide an improvement in SNR of about 1.5 dB compared to the system of Fig. 2, and about 3.5 dB compared to the predetection DFE scheme.

The foregoing is provided for purposes of disclosure of a preferred embodiment of the invention; modifications, changes, additions or deletions to the disclosed systems, devices, techniques and methods may be accomplished without departing from the scope or spirit of the invention.

What is claimed is:

1.   An equalizer for equalizing orthogonally keyed signals, comprising:

      a.   a feedforward filter adapted to process said signals;

      b.   a feedback filter whose output is coupled to the output of the feedforward filter;

      c.   an orthogonal demodulator coupled to the feedforward filter and the feedback filter, and adapted to demodulate the summed output of said filters in order to provide data output;

      d.   an orthogonal remapper coupled to the orthogonal demodulator and the feedback filter for remapping signals provided by the demodulator to correspond to keying symbols, and providing the remapped signals to the feedback filter; and

      e.   soft decision functionality coupled to the output of the feedforward and feedback filters in order to receive the summed output of said filters, render soft decisions, and provide soft decision output to said feedback filter.

2.   An equalizer according to claim 1 in which the orthogonally keyed signals are complementary code keyed signals.

3.   An equalizer according to claim 2 in which the orthogonal remapper is a remodulator and is adapted to provide output to the feedback filter in order to minimize intersymbol interference and to benefit from processing gain of the orthogonally keyed signals to reduce error probability.

4.   An equalizer according to claim 2 in which the soft decision functionality is adapted to provide output to the feedback filter in order to minimize effect of decision errors and inter-chip interference.

5.   An equalizer according to claim 2 in which the soft decision functionality is adapted to render soft decisions according to the function:

$$f(y) = \frac{1}{\sqrt{2}}\left\{\tanh\left[\sqrt{2}\gamma \, \mathrm{Re}(y)\right] + j\tanh\left[\sqrt{2}\gamma \, \mathrm{Im}(y)\right]\right\}$$

where y is the input, whose real part and imaginary parts are denoted by Re(y) and Im(y) respectively, and γ is a parameter which controls the softness of the function.

6.   An equalizer according to claim 5 in which γ is 2.

7.   An equalizer according to claim 5 in which γ is approximately 2.

8.   An equalizer according to claim 5 in which γ is other than 2.

9.   An equalizer according to claim 5 in which γ is determined at least in part based on signal to noise ratio at the output of the equalizer.

10.   An equalizer according to claim 1 in which the soft decision functionality is adapted to render soft decisions using linear approximation.

11.   An equalizer according to claim 1 in which the soft decision functionality is adapted to render soft decisions using a look up table.

12.   A method for equalizing an orthogonally keyed signal, comprising:

        a.   providing said orthogonally keyed signal;

        b.   suppressing interference from future data symbols in said signal and providing the output as future data symbol-interference-suppressed output;

        c.   suppressing interference from past data symbols in said signal using information derived from said orthogonally keyed signals which have been demodulated and providing the output as past data symbol-interference-suppressed output;

        d.   applying said past data symbol-interference-suppressed output and said future data symbol-interference-suppressed output to a soft decision function in order to provide as output additional past data symbol-interference-suppressed output; and

        e.   demodulating said past data symbol-interference-suppressed output and said future data symbol-interference-suppressed output in order to provide demodulated data output.

13.   The method of claim 12 in which suppressing interference from past data symbols in said signal using information derived from said orthogonally keyed signals which have been demodulated and providing the output as past data

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symbol-interference-suppressed output further comprises remapping said demodulated data output to correspond to keying symbols.

14. The method of claim 12 in which suppressing interference from future data symbols in said signal and providing the output as future data symbol-interference-suppressed output is accomplished in a feedforward filter.

15. The method of claim 14 in which suppressing interference from past data symbols in said signal using information derived from said orthogonally keyed signals which have been demodulated and providing the output as past data symbol-interference-suppressed output is accomplished in a feedback filter coupled to the output of said feedforward filter.

16. The method of claim 15 in which applying said past data symbol-interference-suppressed output and said future data symbol-interference-suppressed output to a soft decision function in order to provide as output additional past data symbol-interference-suppressed output, is accomplished in a soft decision functionality whose output is coupled to said feedback filter.

17. The method of claim 15 in which demodulating said past data symbol-interference-suppressed output and said future data symbol-interference-suppressed output in order to provide demodulated data output, is accomplished in a demodulator coupled to the output of said feedforward and said feedback filters.

18. A method for equalizing a complementary code keyed signal, comprising:

a. coupling the signal to a soft decision functionality in order to produce soft decision functionality output, producing feedback information based on said soft decision functionality output, and feeding back to said complementary code keyed signal said soft decision functionality output-based feedback information; and

b. demodulating said signal, which includes said feedback information, in order to provide output data.

19. A method according to claim 18 in which feeding back to said complementary code keyed signal said soft decision functionality output-based

feedback information comprises passing said soft decision functionality output to a feedback filter, and feeding the output of said feedback filter to said complementary code keyed signal.

20.   A method according to claim 18 further comprising:

a.   producing delayed output based on said complementary code keyed signal which includes said soft decision functionality output-based feedback information, and feeding back to said complementary code keyed signal additional feedback information based on said delayed output; and

b.   demodulating said signal, which includes said additional feedback information, in order to provide output data.

21.   A method according to claim 20 in which producing delayed output comprises remapping said output data to produce information corresponding to keying symbols.

22.   A method according to claim 21 in which producing delayed output based on said complementary code keyed signal which includes said soft decision functionality output-based feedback information, and feeding back to said complementary code keyed signal additional feedback information based on said delayed output comprises passing said remodulated information to a feedback filter, and feeding the output of said feedback filter to said complementary code keyed signal.

23.   A method according to claim 22 in which feeding back to said complementary code keyed signal said soft decision functionality output-based feedback information comprises passing said soft decision functionality output to a feedback filter, and feeding the output of said feedback filter to said complementary code keyed signal, and in which said feedback filter to which said remapped information is passed is the same feedback filter to which said soft decision functionality output is passed.

24.   A method according to claim 18 in which the soft decision functionality is adapted to produce decisions using the function:

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$$f(y) = \frac{1}{\sqrt{2}} \left\{ \tanh\left[\sqrt{2}\gamma \, \text{Re}(y)\right] + j \tanh\left[\sqrt{2}\gamma \, \text{Im}(y)\right] \right\}$$

where y is the input, whose real part and imaginary parts are denoted by $\text{Re}(y)$ and $\text{Im}(y)$ respectively, and γ is a parameter which controls the softness of the function.

25.   A method according to claim 24 in which γ is 2.

26.   A method according to claim 24 in which γ is approximately 2.

27.   A method according to claim 24 in which γ is other than 2.

28.   A method according to claim 24 in which γ is determined at least in part based on signal to noise ratio of the feedback information.

29.   An equalizer according to claim 24 in which the soft decision functionality is adapted to render soft decisions using linear approximation.

30.   An equalizer according to claim 24 in which the soft decision functionality is adapted to render soft decisions using a look up table.

31.   A method according to claim 18 further comprising filtering said complementary code keyed signal before it is passed to said soft decision functionality, and before said feedback information is fed back into said complementary code keyed signal, in order to suppress interference from future data symbols in said complementary code keyed signal.

32.   A method according to claim 18 in which feeding back to said complementary code keyed signal said soft decision functionality output-based feedback information is accomplished in order to reduce inter-character interference in said complementary code keyed signal.

33.   A transceiver which includes an equalizer for equalizing orthogonally keyed signals, comprising:

    a.   a feedforward filter adapted to process said signals;

    b.   a feedback filter whose output is coupled to the output of the feedforward filter;

c.   an orthogonal demodulator coupled to the feedforward filter and
the feedback filter, and adapted to demodulate the summed output of said filters
in order to provide data output;

d.   an orthogonal remapper coupled to the orthogonal demodulator
and the feedback filter for remapping signals provided by the demodulator to
information corresponding to keying signals, and providing the remapped
information to the feedback filter; and

e.   soft decision functionality coupled to the output of the feedforward
and feedback filters in order to receive the summed output of said filters, render
soft decisions, and provide soft decision output to said feedback filter.

34.   An transceiver according to claim 33 in which the orthogonally keyed
signals are complementary code keyed signals.

35.   A transceiver according to claim 34 in which the soft decision functionality
is adapted to render soft decisions according to the function:

$$f(y) = \frac{1}{\sqrt{2}}\left\{\tanh\left[\sqrt{2}\gamma\,\mathrm{Re}(y)\right] + j\tanh\left[\sqrt{2}\gamma\,\mathrm{Im}(y)\right]\right\}$$

where y is the input, whose real part and imaginary parts are denoted by Re(y)
and Im(y) respectively, and γ is a parameter which controls the softness of the
function.

36.   A transceiver according to claim 35 in which γ is 2.

37.   A transceiver according to claim 35 in which γ is approximately 2.

38.   A transceiver according to claim 35 in which γ is other than 2.

39.   A transceiver according to claim 35 in which γ is determined at least in
part based on signal to noise ratio at the output of the equalizer.

40.   A transceiver according to claim 33 in which the soft decision functionality
is adapted to render soft decisions using linear approximation.

41.   A transceiver according to claim 33 in which the soft decision functionality
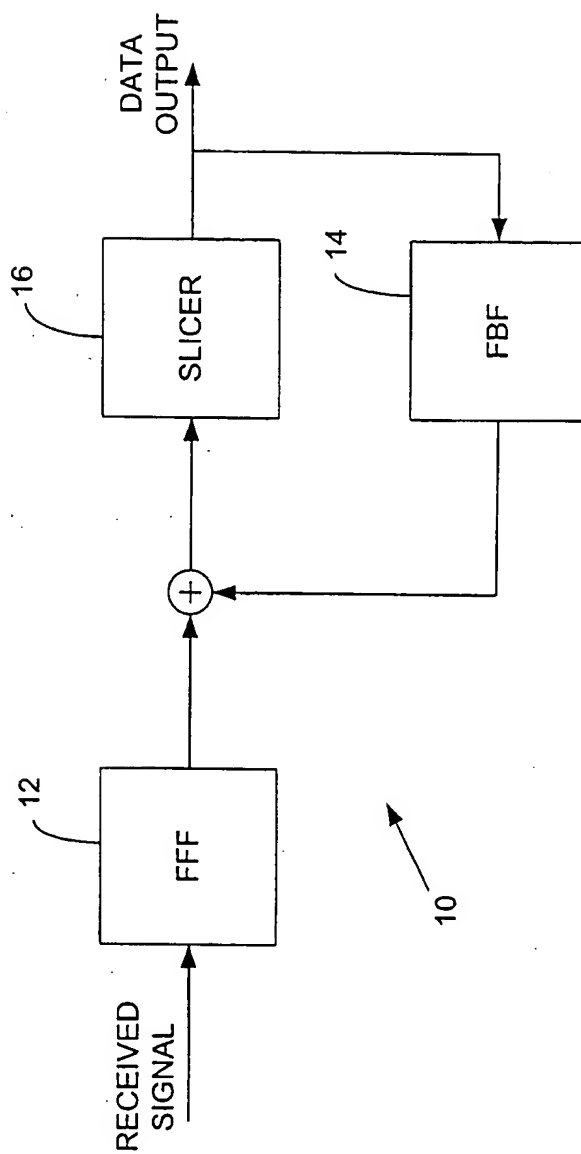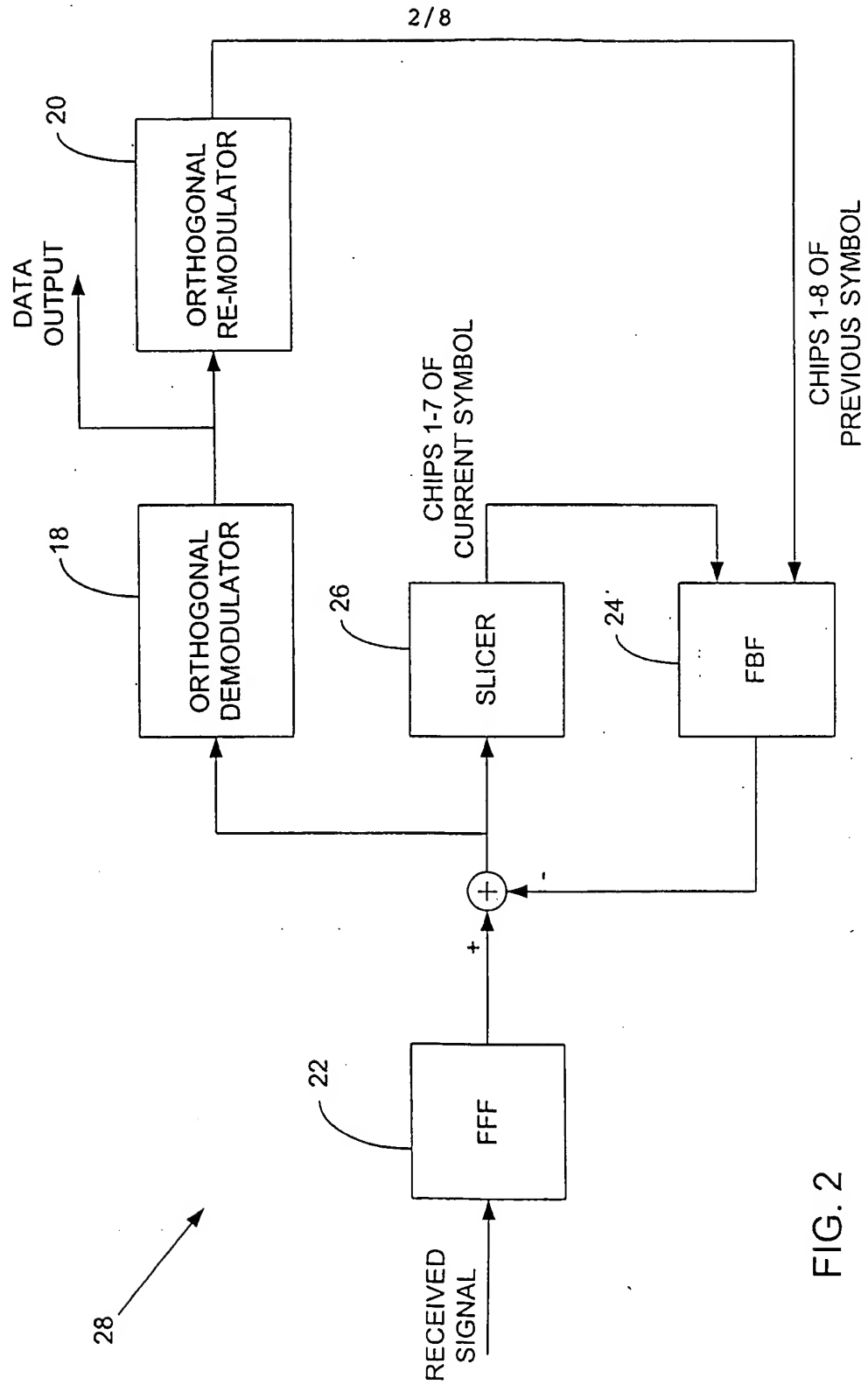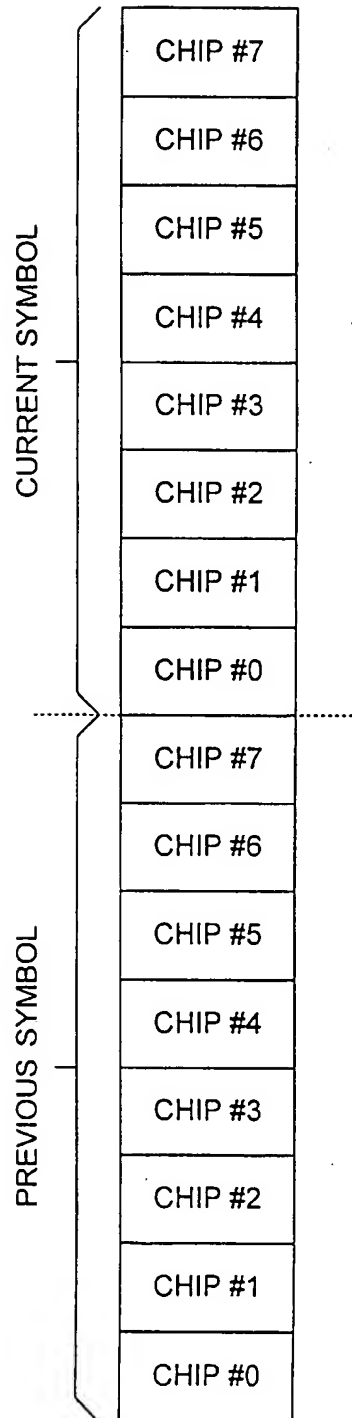is adapted to render soft decisions using a look up table.
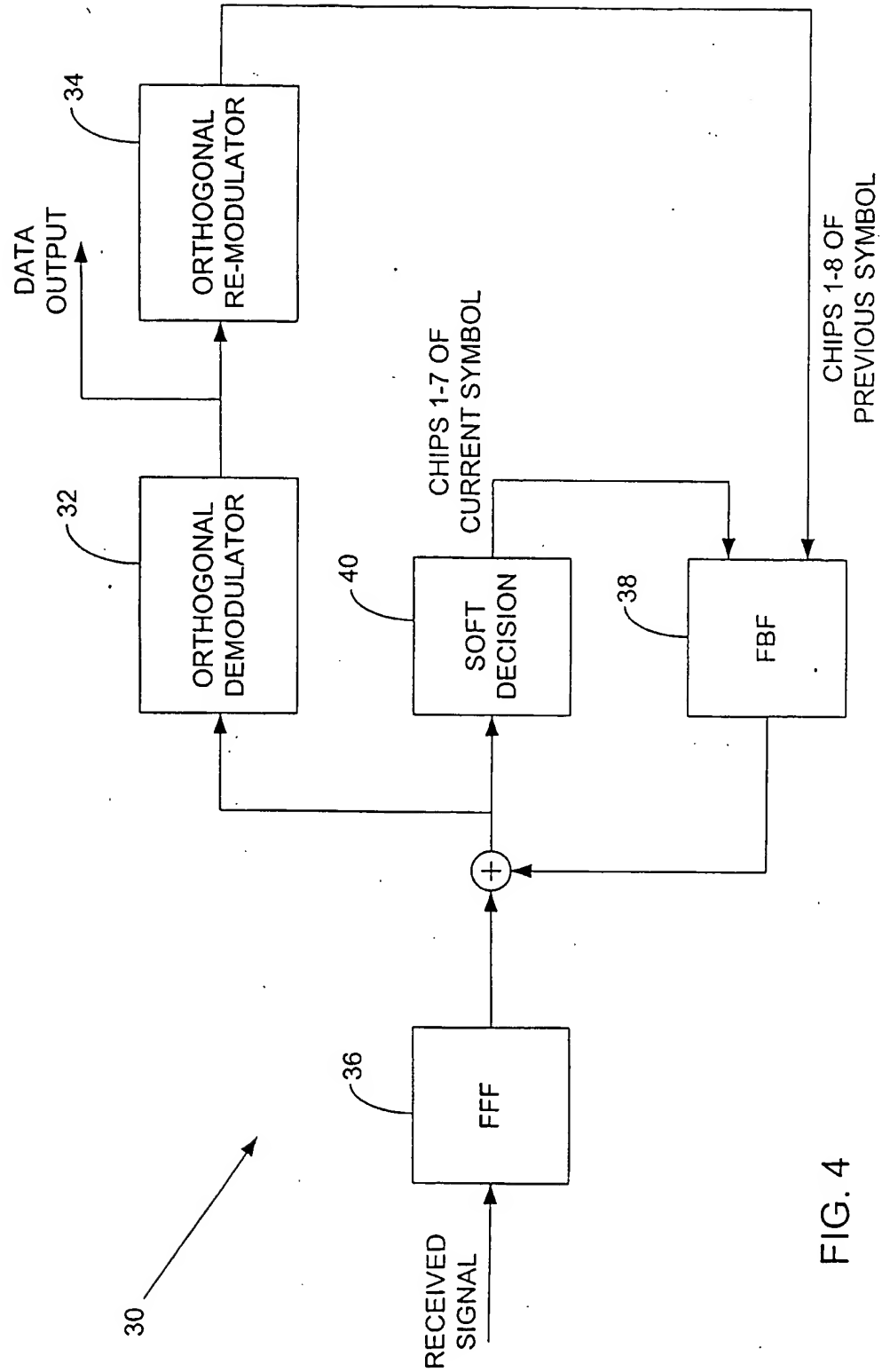
FIG. 1

FIG. 2
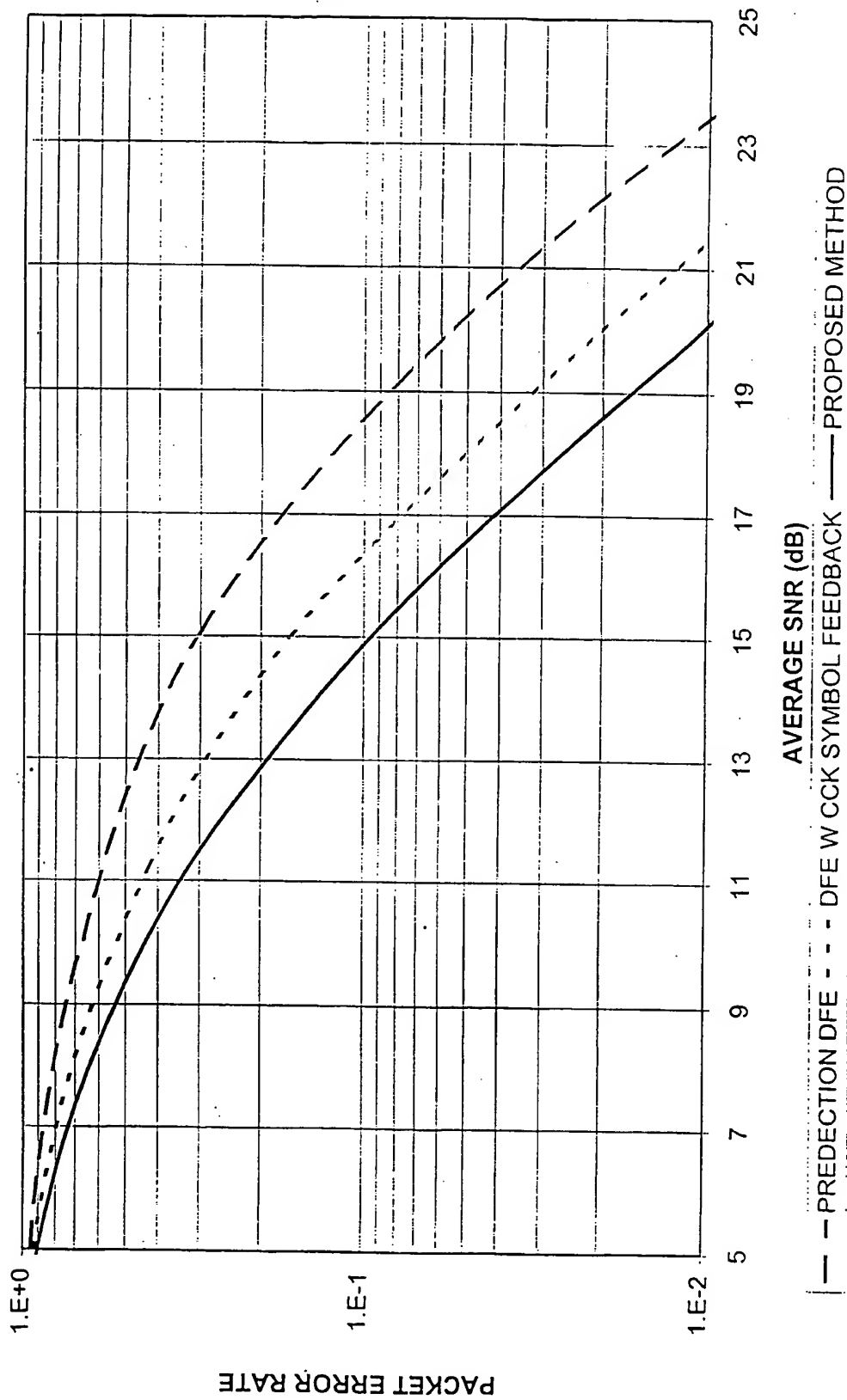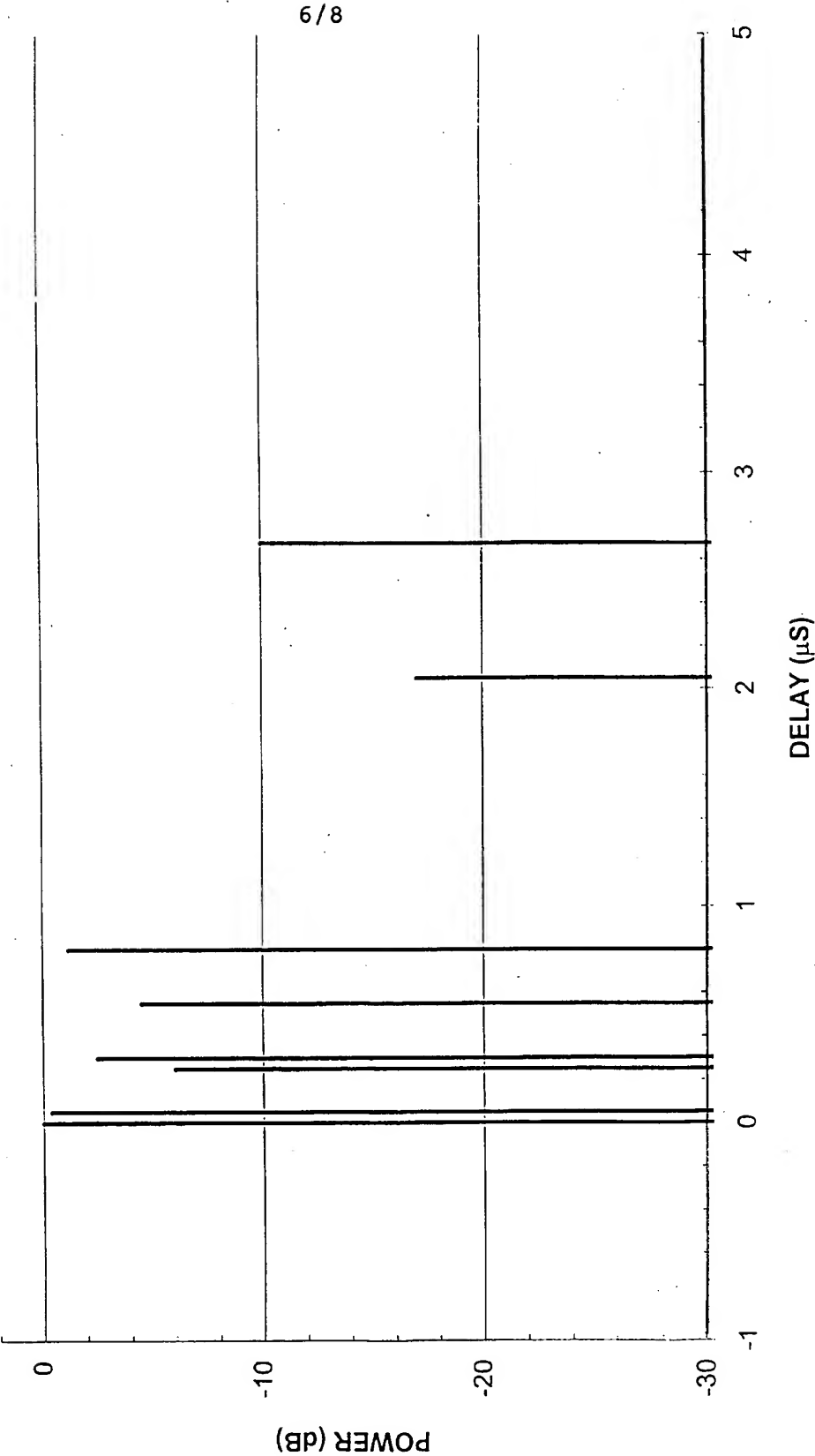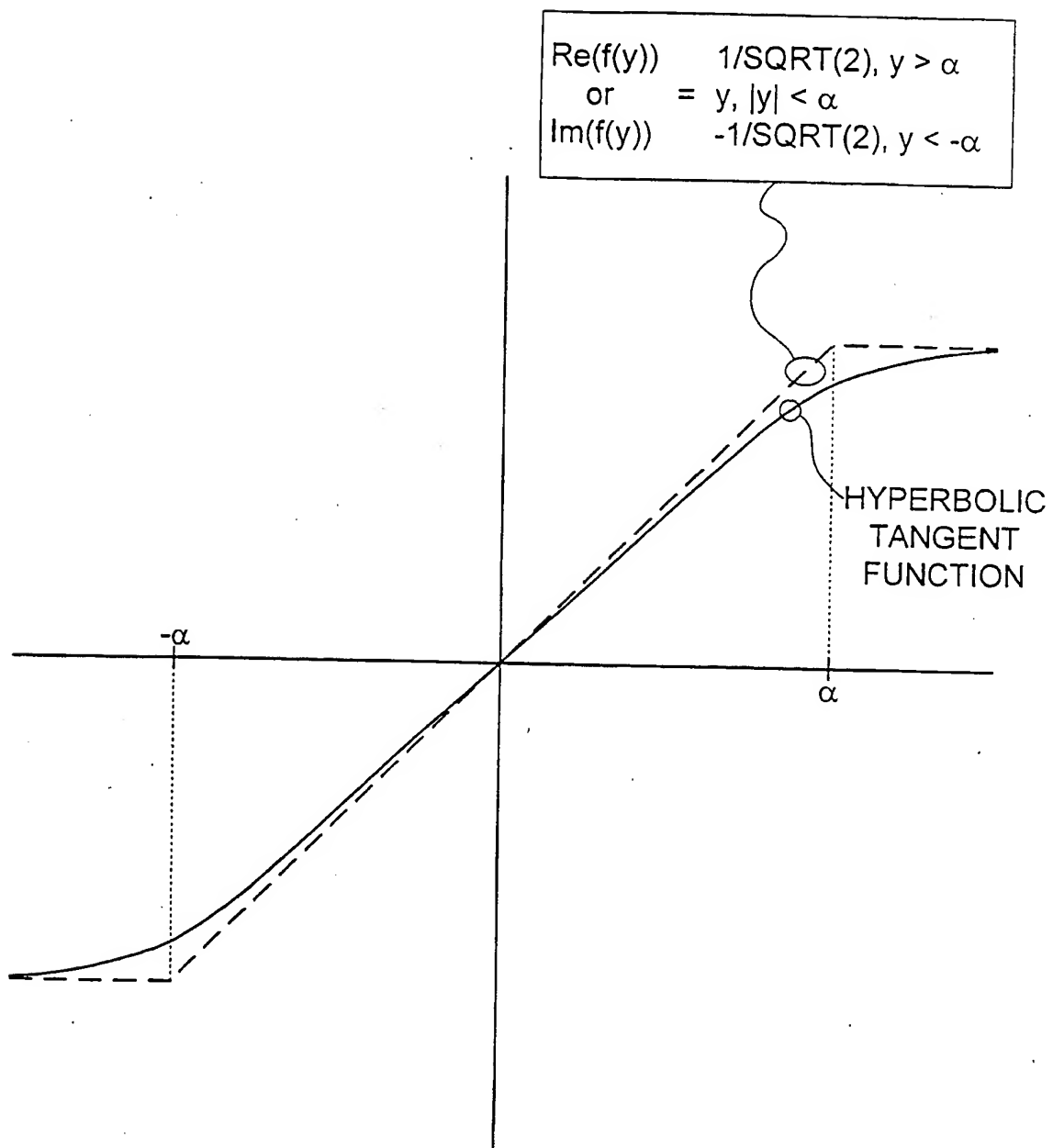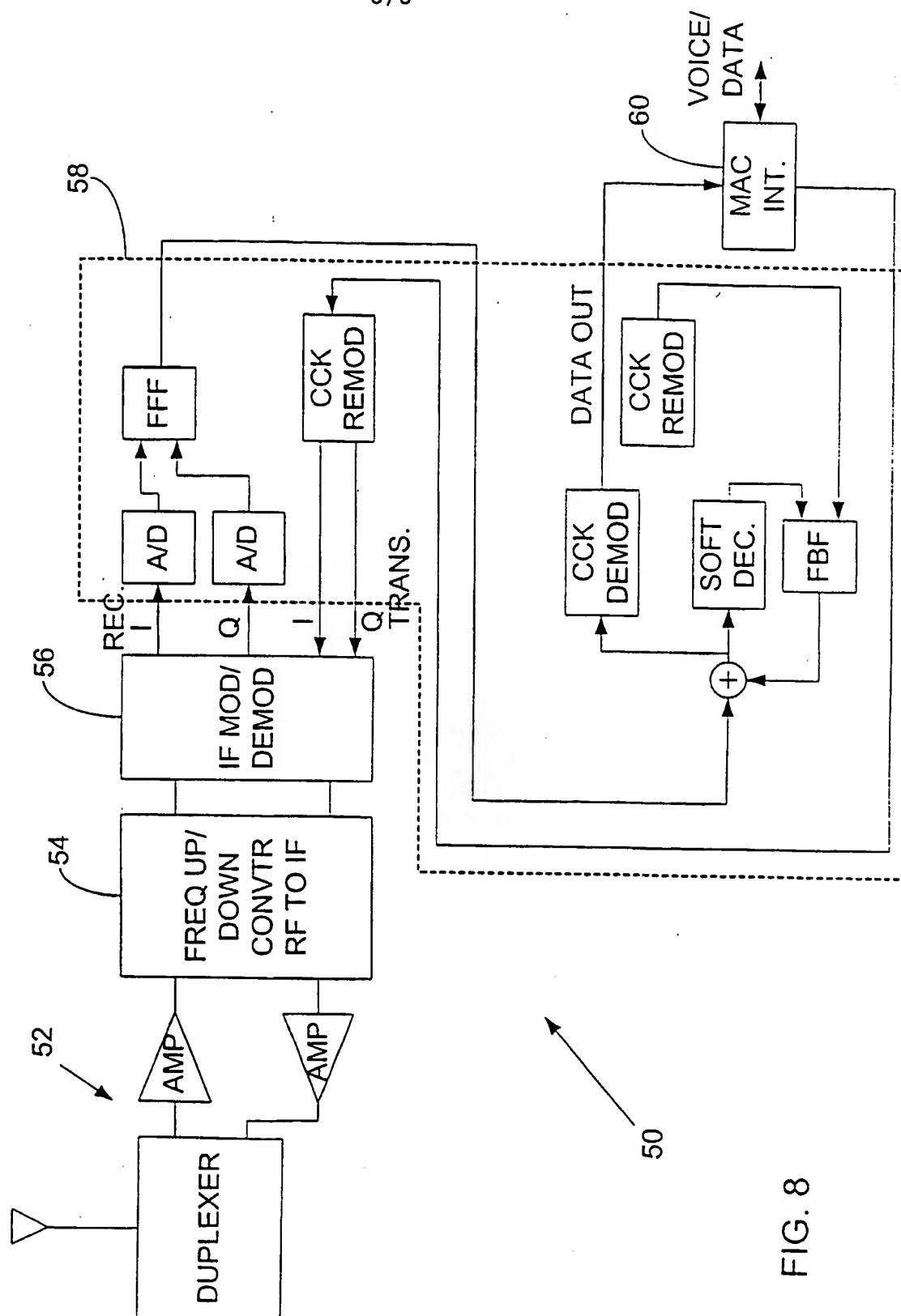
FIG. 3

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FIG. 4

FIG. 5

FIG. 6

POWER (dB)

DELAY (µS)

$$\begin{array}{ll} \text{Re}(f(y)) & 1/\text{SQRT}(2), \ y > \alpha \\ \text{or} \qquad = & y, \ |y| < \alpha \\ \text{Im}(f(y)) & -1/\text{SQRT}(2), \ y < -\alpha \end{array}$$

HYPERBOLIC
TANGENT
FUNCTION

$-\alpha$

α

FIG. 7

FIG. 8

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   H04L25/03   H04L23/02   H04L25/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7   H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WANG T ET AL: "IMPROVED ADAPTIVE DECISION-FEEDBACK EQUALIZATION WITH INTERLEAVING FOR CODED MODULATION SYSTEMS" PROCEEDINGS OF THE GLOBAL TELECOMMUNICATIONS CONFERENCE (GLOBECOM),US,NEW YORK, IEEE, 28 November 1994 (1994-11-28), pages 6-10, XP000488508 ISBN: 0-7803-1821-8 abstract page 6, column 2, line 49 —page 7, column 1, line 5 page 7, column 1, line 20 — line 28; figure 2 paragraph 'CONCLUSION!	1-41

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[X] Further documents are listed in the continuation of box C.		Patent family members are listed in annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 September 2000	29/09/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Binger, B

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INTERNATIONAL SEARCH REPORT

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
P,A	CARL ANDREN,MARK WEBSTER: "CCK Modulation delivers 11 Mbps for high Rate IEEE 802.11 Extension" INTERNET, 14 March 2000 (2000-03-14), pages 1-8, XP002147321 page 1, line 31 -page 2, line 26 page 5, line 41 - line 45 page 7; figures 14,15	1-41

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